The Properties of Convective Clouds over the Western Pacific and Their Relationship to the Environment of Tropical Cyclones (No-cost extension)

Principal Investigator: Zhaoxia Pu
Department of Atmospheric Sciences, University of Utah
135 S 1460 E, Rm. 819
Salt Lake City, UT 84112
Phone: (801)585-3864 Fax: (801)585-3681 Email: Zhaoxia.Pu@utah.edu

Collaborators: Carolyn Reynolds and Allen Zhao
Marine Meteorological Division, Naval Research Laboratory (NRL)
7 Grace Hopper Ave
Monterey, CA 93943

Award Number: N000140810308

LONG-TERM GOALS

The long-term goal of the proposed work is to advance our understanding of the relationship between large-scale and mesoscale environmental conditions and small but powerful convective events during tropical cyclone (TC) development and intensity changes. Our ultimate goal is to identify the necessary conditions that determine the formation and evolution of a TC.

OBJECTIVES

Using data obtained from the western Pacific region during "Tropical Cyclone Structure 2008" (TCS-08), ONR's field program, this study proposes to investigate large-scale environmental conditions, mesoscale phenomena, and small-scale convective bursts, as well as their interactions that are responsible for TC formation and intensity changes. Specific objectives include 1) characterizing the intensity of convection over the western Pacific using radar, aircraft, and satellite data; 2) deriving an accurate mesoscale environment of convective systems through the assimilation of satellite, radar, lidar, and in-situ data; 3) evaluating the quality of the global forecast system (e.g., Navy Operational Global Atmospheric Prediction System, or NOGAPS) for accurate TC analyses and forecasts; and 4) understanding the environmental factors that determine tropical cyclone formation and rapid intensification.

APPROACH

In order to achieve the research objectives of this proposal, our approach integrates observational data analysis, mesoscale data assimilation, and forecast evaluations. This includes 1) analyzing TCS-08 field data in conjunction with the available satellite data products from the NASA Aqua and Tropical Rainfall Measuring Mission (TRMM); 2) producing mesoscale numerical simulations by assimilating satellite, radar, lidar, and in-situ data into the Weather Research and Forecasting (WRF) and the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2013		**00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The Properties of Convective Clouds over the Western Pacific and Their Relationship to the Environment of Tropical Cyclones (No-cost extension)	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Utah,Department of Atmospheric Sciences,135 S 1460 E, Rm. 819,Salt Lake City,UT,84112**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS®) mesoscale models; and 3) evaluating the performance of global ensemble forecasting to understand the quality of global forecasts and also study the predictability of TC formation and evolution.

People involved in this project in FY13 include the PI (Prof. Zhaoxia Pu), her graduate students (Levi Thatcher and Zhan Li), and NRL collaborators (Drs. Carolyn Reynolds and Allen Zhao).

WORK COMPLETED

Work completed in FY13 includes:

- Continuation of mesoscale numerical simulations of TCS-08 major typhoons with data assimilation. Specific efforts were made to understand the role of intense convection in the formation of Typhoon Nuri (2008).
- Examination of the impact of radar data assimilation on numerical simulation of Typhoon Nuri (2008). Specifically, assimilation of radar derived 3-dimentional winds versus direct assimilation of radar radial velocity is compared.
- Evaluation of tropical cyclone genesis precursors with relative operating characteristics (ROC) in high-resolution ensemble forecasts.
- Characteristics of tropical cyclone genesis forecast and underdispersion in high-resolution ensemble forecasting with a stochastic kinetic energy backscatter scheme.

RESULTS

(1) The role of intense convection in the genesis of Typhoon Nuri (2008)

Progress has been continued to examine the process that controls Typhoon Nuri's genesis. The role of intense convection is examined. First, compared the differences between the genesis and nongenesis cases in numerical simulations with various initial conditions and forecast lead times, it is found that the development of intense convection near the circulation center is a key factor that distinguishes the developing versus nondeveloping disturbance associated with Nuri's genesis. Specifically, in the developing case, convections propagate and organize into a "pouch" center of a westward-propagating wave-like disturbance. In the nondeveloping case, the convections fail to develop and organize. Favorable conditions for the development of deep convections include strong closed circulation with high humidity, especially at the middle levels. Results also confirm that the enhancement of mid- to upper-level moisture is favorable for Nuri's genesis, mainly because moist conditions benefit deep convection, which produces diabatic heating from latent heat release when vertical air mass flux maxima occur in the mid- to upper-level atmosphere. The substantial warming at upper levels induced by latent heat release from persistent deep convection contributes to the drop in Nuri's minimum central sea level pressure (See details in Li and Pu 2013 JGR).

COAMPS® is a registered trademark of the Naval Research Laboratory.

(2) The impact of radar data assimilation on numerical simulation of Typhoon Nuri: retrieved winds versus direct assimilation of radial velocity

Initial conditions have a significant impact on forecasts of tropical cyclone (TC) genesis in numerical weather prediction. Data assimilation experiments were conducted using the WRF model and its four-dimensional variational data assimilation (4D-Var) system to examine the impacts of radar data assimilation on numerical simulations of the genesis of Typhoon Nuri (2008). Radar observations collected from the ELDORA airborne radar during the ONR Tropical Cyclone Structure 2008 (TCS-08) field program, were assimilated into the WRF model for improving the atmospheric conditions in the pre-genesis phase of Typhoon Nuri. Two ways of assimilating the radar wind data were performed: one assimilated the radar wind analysis retrieved from a 3-dimensional variational method; the other directly assimilated the radar radial velocity.

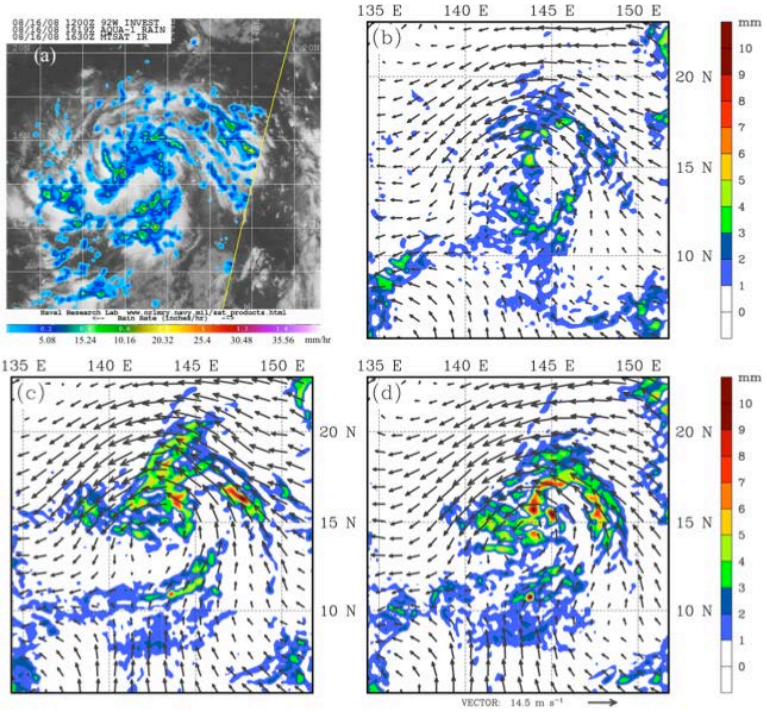

Figure 1. The hourly rainfall rate derived from a) NASA Aqua satellite measurements at 1619 UTC 16 August 2008 (top left panel, courtesy of NRL TC web page), b) control simulation without assimilating radar observations (top right pane), and c) simulations with assimilating radar wind analysis (bottom left) and radar radial velocity (bottom right) at 1600 UTC 16 August 2008. The figure demonstrates that radar data assimilation significantly improves the convection and precipitation forecasts in TC genesis environment. Compare with assimilation of radar wind analysis, direct assimilation of radar radial velocity result in more realistic precipitation forecasts.

Results show that the 4DVAR assimilation of radar wind observations significantly improves the model simulations of Nuri's genesis. The simulations with the radar data assimilation (both assimilating the radar wind analysis and the radial velocity) produce Nuri's genesis with enhanced storm intensity, while the control experiment (without radar data assimilation) fails to predict Nuri's genesis. In addition, by comparing two assimilation methods, it is found that the assimilation of the radial velocity leads to more improvement in Nuri's intensity forecasts, while the track forecasts are

better improved with the assimilation of the radar wind analysis. Further diagnosis indicated that the radar data assimilation results in the enhanced middle-level vortex and moist conditions in pre-Nuri environments thus provide favorable conditions for the development of deep convection (See details in PhD dissertation of Zhan Li).

(3) Evaluation of tropical cyclone genesis precursors with relative operating characteristics (ROC) in high-resolution ensemble forecasts

Identifying the environmental conditions that control tropical cyclone (TC) genesis is a challenging problem. A new method is examined to evaluate the precursors of TC genesis using high-resolution ensemble forecasts and relative operating characteristic (ROC) diagrams.

With WRF model, high-resolution ensemble forecasts (at 5 km horizontal resolution) are conducted in various configurations using a bred vector method to form a set of 140 ensemble members for predicting the genesis of Hurricane Ernesto (2006). Basic evaluation shows that high-resolution ensemble forecasts are able to predict well-developed TCs, whereas the NCEP Global Ensemble Forecast System (GEFS) fails to do so. This set of 140 ensemble members is employed to study the precursors of Hurricane Ernesto's genesis by contrasting the genesis and nongenesis cases. Specifically, ROC curves, composite figures for genesis and nongenesis cases, and Kolmogorov-Smirnov tests are applied to characterize the relationship between important environmental parameters near the beginning of the simulation and genesis likelihood 15-18 h later. It is found that moist conditions at 850 hPa, vertical wind shear, the strength of the 850 hPa pre existing wave, and upper-level warming play notable roles in Ernesto's genesis (see details in Thatcher and Pu 2013 TCRR).

(4) Characteristics of tropical cyclone genesis forecast and underdispersion in high-resolution ensemble forecasting with a stochastic kinetic energy backscatter scheme

The ensemble forecasts with a stochastic kinetic energy backscatter scheme (SKEBS) in predicting tropical cyclone (TC) genesis is evaluated. The related ensemble underdispersion is also examined. Specifically, several sets of ensemble forecasts are generated using an advanced research version of Weather Research and Forecasting (WRF) model at 5 km horizontal resolution to predict the genesis of Hurricane Ernesto (2006). Ensemble forecasts with SKEBS are compared against a control ensemble forecast (CNTL) with WRF model using initial conditions derived from NCEP Global Ensemble Forecasting System. A similar ensemble forecast with SKEBS, 18 h ahead of the genesis of Typhoon Nuri is also conducted.

It is found that ensemble forecasts with SKEBS are able to generate probabilistic forecasts for TC genesis that are compatible with initial perturbation-based ensemble forecasts. They are also capable of indicating the forecast uncertainties, as variations of flow patterns among ensemble members are clearly seen. Compared with the deterministic forecast that fails to predict the genesis of Typhoon Nuri, the ensemble forecast with SKEBS is able to produce the genesis forecast in 8 members out of the total 14 ensemble members.

The underdispersion of ensemble forecasts with SKEBS is also characterized in terms of simulation period and over the whole model domain, TC environment and inner core regions. It is found that the underdispersion is presented in all cases but more serious over the TC inner core region. Despite of the limited sample size of ensemble forecasting due to computational resources, inadequacy of using

SKEBS solely in TC genesis environment is evident. (See Levi Thatcher's PhD dissertation for details).

IMPACT/APPLICATIONS

Data assimilation, numerical simulations, and ensemble forecasting aid in understanding the predictability of TCs and the conditions those contribute to TC formation and intensity changes. Evaluation of ROC method in detecting TC genesis precursors provides new insights in identifying the conditions that influence TC genesis. The findings from the high-resolution ensemble forecasts with a stochastic kinetic energy backscatter scheme (SCKEBS) are helpful for understanding the ensemble forecasts with SKEBS in TC genesis environment.

PUBLICATIONS

1. *Peer-reviewed journal articles*

- Li, Z. and Z. Pu, 2013: Numerical simulations of the genesis of Typhoon Nuri (2008): the roles of intense convection and moisture conditions. *J. Geophy. Res.,* (Conditionally accepted)
- Thatcher, L. and Z. Pu , 2013: Evaluation of tropical cyclone genesis precursors with relative operating characteristics (ROC) in high-resolution ensemble forecasts: Hurricane Ernesto. *Tropical Cyclone Research and Review*, (in press).
- Zhang, H. and Z. Pu , 2013: Impact of surface observations on the predictability of landfalls of Hurricane Katrina (2005) with ensemble-based data assimilation. *Mon. Wea. Rev.*, Submitted.
- Li, Z., and Z. Pu, 2013: Impact of the 4D-Var assimilation of Airborne Doppler Radar data on numerical simulations of the genesis of Typhoon Nuri (2008). *Mon. Wea. Rev.* (in preparation)

2. *Graduate student dissertations*

- Levi Thatcher, 2013: *High-resolution ensemble error growth and dimensionality in tropical cyclone genesis environments.* Ph.D. Dissertation. University of Utah, 250pp
- Zhan Li, 2013: *Studying the genesis of Typhoon Nuri (2008) with high-resolution numerical simulations and data assimilation.* Ph.D. Dissertation. University of Utah, 170pp

3. *Conference papers and presentations*

- Li, Z., and Z. Pu, 2013: Impact of the 4D-Var assimilation of Airborne Doppler Radar data on numerical simulations of the genesis of Typhoon Nuri (2008). *14th Annual WRF Users' Worksho*p. Boulder, CO, June 24-28, 2013
- Pu, Z., H. Zhang, and L. Zhang, 2013: Assimilation of satellite and radar data toward improving numerical simulations of tropical cyclones. *European Geosciences Union, General Assembly 2013*, Vienna, Austria, April 07-12, 2013
- Pu, Z., and H. Zhang, 2013: "*The impact of ensemble-based data assimilation on the predictability of landfalling hurricanes". 67th Interdepartmental Hurricane Conference, Tropical cyclone Research Forum.* College Park, MD, March 5-7, 2013,
- Pu, Z., C. Velden, S. Aberson, and C. Reynolds, 2013: Assimilation of satellite data in improving numerical simulations of tropical cyclones: Lessons learned from field programs in last decade. *Special Symposium on the Joint Center for Satellite Data Assimilation. 93rd AMS*

Annual Meeting. Austin, TX. January 05-10, 2013

- Zhang, H. and Z. Pu, 2013: The impact of Ensemble-based data assimilation on the predictability of landfalling Hurricane Katrina (2005), *17th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface. 93rd AMS Annual Meeting*. Austin, TX. January 05-10, 2013
- Thatcher, L., and Z. Pu, 2013: Studying error growth in the tropical cyclone genesis environment with mesoscale high-resolution ensemble forecasts, *Symposium on the Role of Statistical Methods in Weather and Climate Prediction*, *93rd AMS Annual Meeting*. Austin, TX. January 05-10, 2013